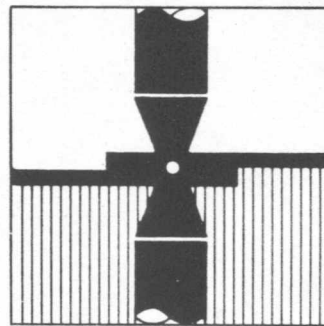


CHAPTER 7

RESISTANCE-WELDING PROCESSES



Resistance welding consists of a group of processes (Figure 7-1) in which the heat required for welding is generated by the resistance of the parts to the passage of an electric current. It differs from the fusion-welding processes in that it requires, in addition to heat, the application of mechanical pressure to forge the parts together. The pressure refines the grain structure and produces a weld with physical properties that in most cases are equal, and sometimes even superior, to those of the base metal.

Resistance-welding equipment is classified according to its electrical operation—as direct-energy or as stored-energy type. Although both single-phase and three-phase welding machines are commercially available, the single-phase, direct-energy machine is the most commonly used, because it is the simplest and least expensive in terms of acquisition cost, installation, and maintenance.

The electrical system of a single-phase ac resistance-welding machine (Figure 7-2) consists of transformers, top switch, and secondary circuit, including electrodes. The electrical energy used by the electrodes is taken directly from the power line, like water from a fire hydrant.

Sufficient voltage must be available in the electrical system to provide the current required to furnish sufficient heat to produce a weld (Figure 7-3) of the required size.

The voltage needed to produce the required current is determined by the geometry of the secondary loop (Figure 7-4), the electrical

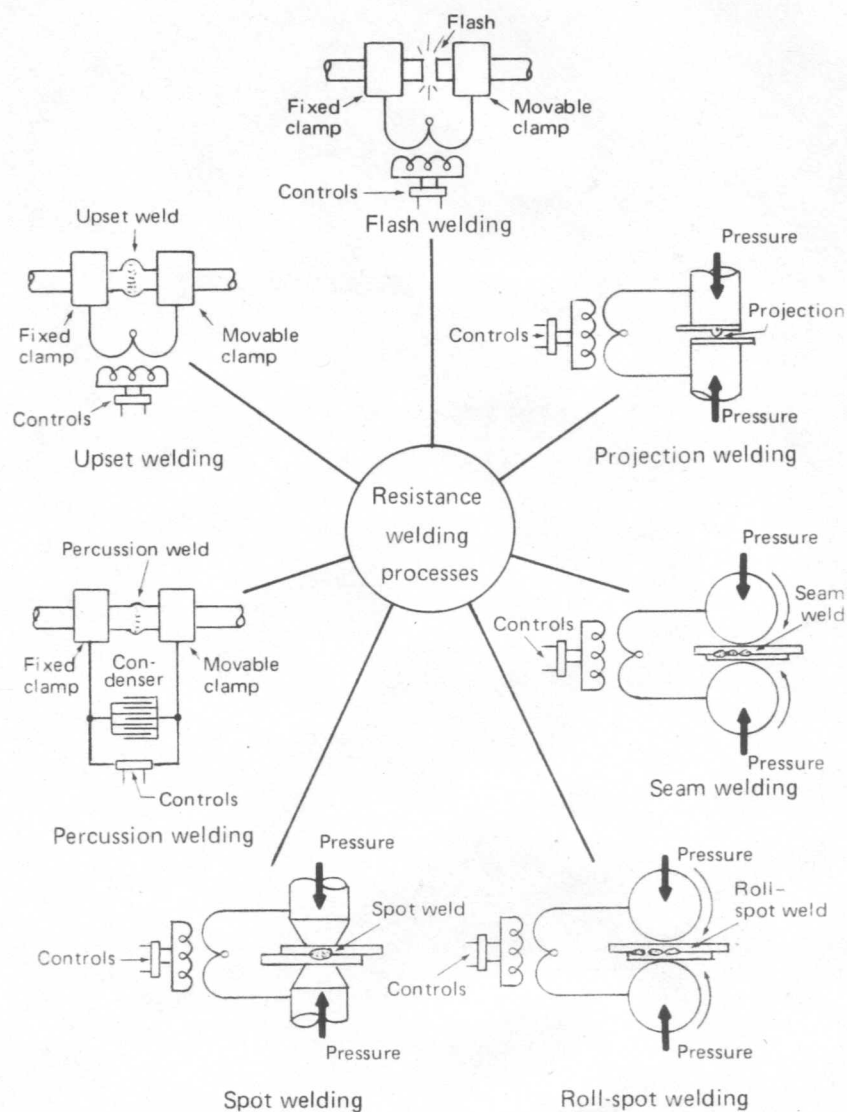


Figure 7-1 The resistance-welding processes. (Redrawn from *Welding Engineering* by Boniface E. Rossi. Copyright 1954 McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company.)

conductivity of the conductor in the circuit, the contact joint resistance, and the resistance of the work. The required voltage is referred to as the *secondary open-circuit voltage* and, when multiplied by the welding current and divided by 1000, gives the demand kVA of the welding transformer. The term kVA is used in the resistance-welding industry to express the work capability of the

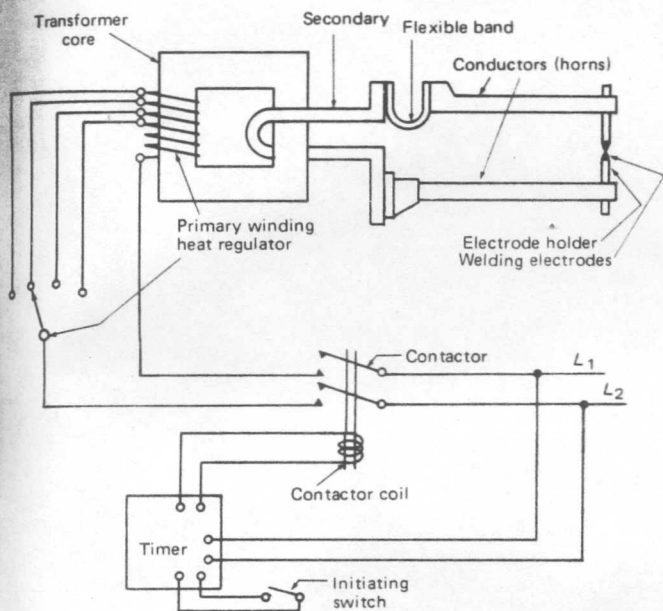


Figure 7-2 Schematic of a single-phase ac resistance-welding machine. (Redrawn from *Welding Engineering* by Boniface E. Rossi. Copyright 1954 McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company.)

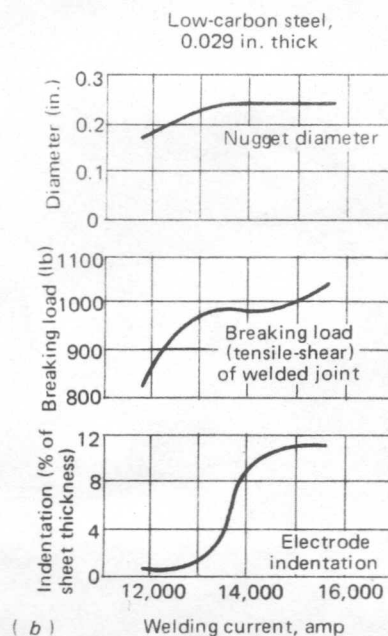
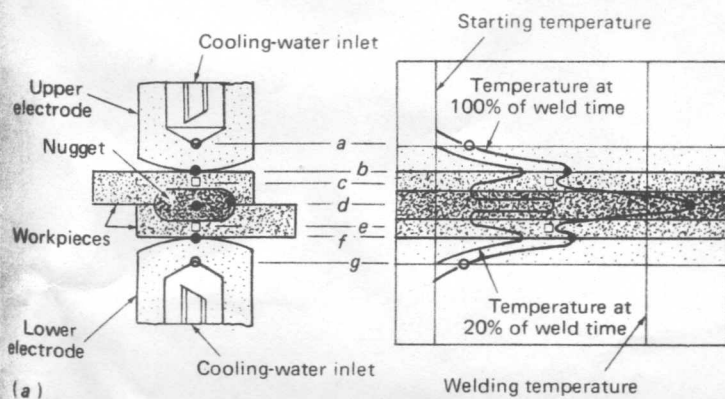
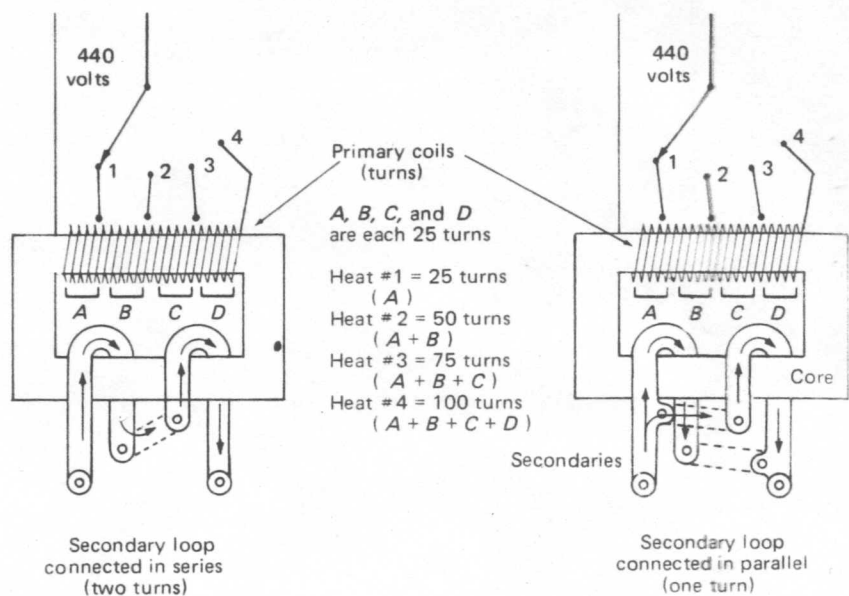


Figure 7-3 (a) Major points of heat generation in resistance spot-welding. (b) Effects of welding current on nugget diameter, tensile shear strength, and electrode indentation in resistance spot-welding. (By permission, from *Metals Handbook* Volume 6, Copyright American Society for Metals, 1971.)



Secondaries in parallel		Secondaries in series	
Heat #1	$\frac{440}{25} = 17.6$ volts	$\frac{440}{12.5} = 35.2$ volts	
Heat #2	$\frac{440}{50} = 8.8$ volts	$\frac{440}{25} = 17.6$ volts	
Heat #3	$\frac{440}{75} = 5.9$ volts	$\frac{440}{37.5} = 11.7$ volts	
Heat #4	$\frac{440}{100} = 4.4$ volts	$\frac{440}{50} = 8.8$ volts	

Using Ohm's law: $I = \frac{E}{Z}$

(I = current; E = voltage Z = impedance)

In an example where the impedance is 0.00044 ohms and the secondary voltage (heat - 4) = 4.4:

$$I = \frac{4.4}{0.00044} = 10,000 \text{ secondary amps}$$

$$\text{(If } E = 8.8) \quad I = \frac{8.8}{0.00044} = 20,000 \text{ secondary amps}$$

Figure 7-4 Effect of the geometry of the secondary loop on heat generation. (Redrawn from *Resistance Welding, Designing, Tooling and Applications* by W. A. Stanley. Copyright 1950 McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company.)

welding machine, or duty cycle. The *work capability* involves not only how big a weld the machine can produce, but also how often it can produce such welds without "burning out" its transformer or related equipment.

The duty cycle of a resistance-welding transformer is defined as the percentage of time in each one-minute period that the transformer is actually carrying current. It is standard practice to rate

resistance-welding transformers on a 50% duty cycle. This means that all resistance-welding machines (except seam welders) can be used at their maximum kVA rating indefinitely for 30 seconds out of every minute without causing excessive heating of the transformer.

Dirt, rust, and other foreign matter on the surfaces of the parts to be joined increases the resistance to electric current and must therefore be removed. Because the mechanical (dirt) and chemical (rust) films are in no way similar, different methods must be employed to remove them. Metal manufacturers can usually provide thorough information on the correct cleaning method to be used for a particular metal.

7-1 SPOT WELDING

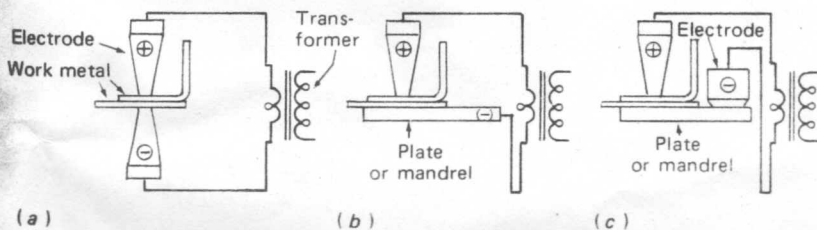
Spot welding is the most widely used form of resistance welding. The three variations of the basic process are shown in Figure 7-5.

In its simplest application [Figure 7-5(a)], spot welding consists merely of clamping two or more pieces of sheet metal between two copper or copper-alloy welding electrodes and passing electric current of sufficient strength through the pieces to cause welding or bonding of the pieces.

A pictorial sequence of the making of a spot weld and the resultant spot is given in Figure 7-6. The sequence consists of:

- **Squeeze time.** The time between the initial application of the electrode pressure on the work, and the first application of current in making spot and seam welds by resistance welding and in projection or upset welding.
- **Weld time.** The time that the welding current flows through the parts being welded, usually expressed in cycles. For example, in welding a 0.125-inch-thick assembly of SAE 1010 with a frequency of 60 Hz (hertz), the weld time would be 10 cycles or $10 \text{ c}/60 \text{ Hz (c/s)} = \frac{1}{6} \text{ s}$.

Figure 7-5 Three arrangements of workpiece and electrodes in resistance spot-welding. (By permission, from *Metals Handbook* Volume 6. Copyright American Society for Metals, 1971.)



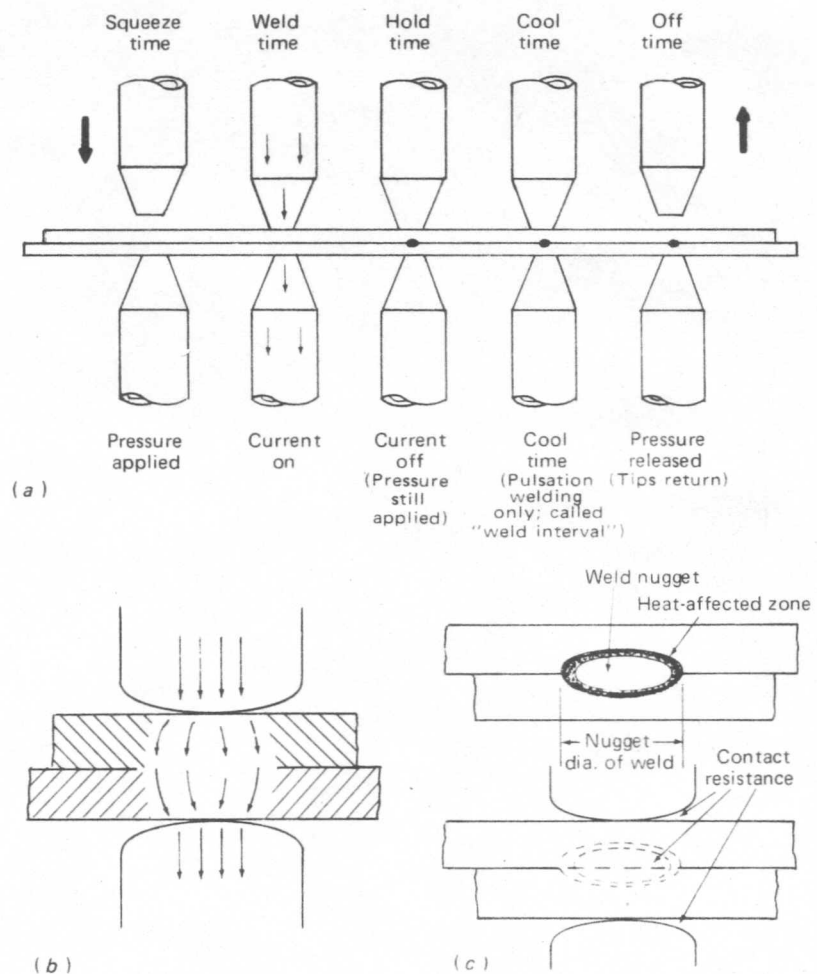


Figure 7-6 (a) Pictorial sequence of the making of a spot weld. (b) Path of the welding current in a spot weld. (c) Heat-affected zone in relation to weld nugget. (Redrawn from *Resistance Welding, Designing, Tooling and Applications* by W. A. Stanley. Copyright 1950 McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company.)

- **Hold time.** The time during which pressure is applied at the point of welding after the welding current has ceased to flow. The hold time is used to allow the plastic weld nugget to cool or harden, after which the pressure is released and the tip is retracted. Figure 7-7 is a graphical representation of the same sequence.

To make a weld with three-phase power supplies, some metals, such as alloy steel, magnesium, and Ni-Cr-Fe-Ti (Inconel), require

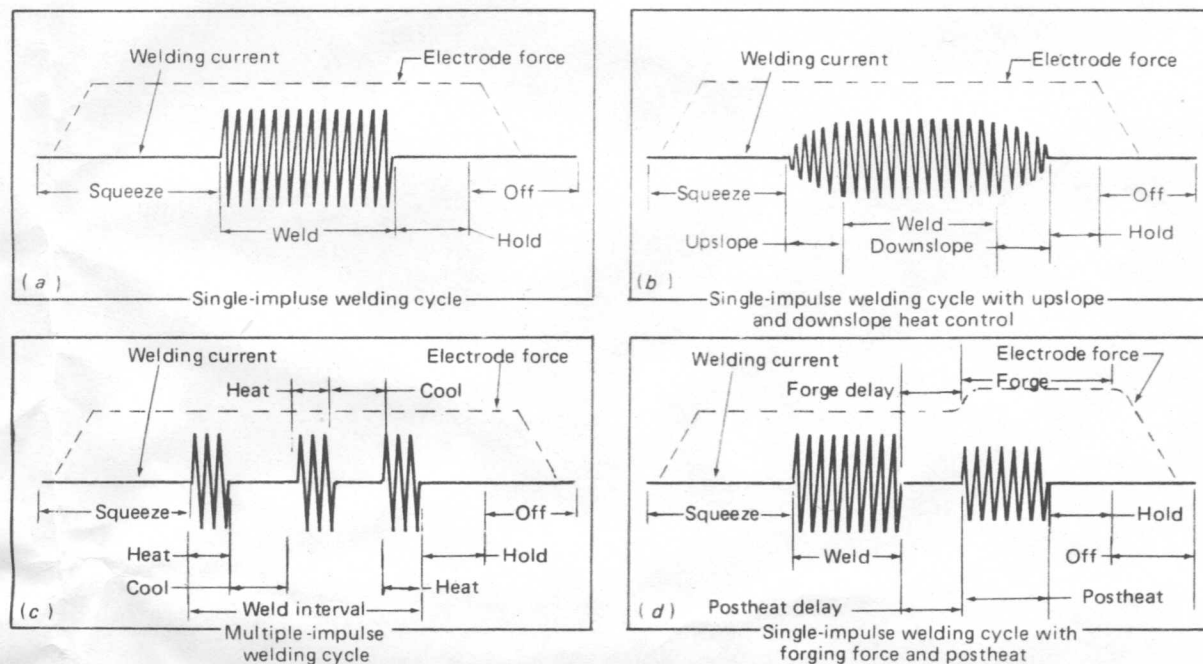
several impulses of current while the electrodes are still closed. This is called *multiple-impulse* or *pulsation* welding when applied to the spot- or projection-welding process, and *interrupted timing* when applied to the seam-welding process.

Standardized, general-purpose spot-welding machines include rocker-arm machines, press-type spot machines, and projection-welding machines.

The rocker-arm machine (Figure 7-8) is the simplest and most commonly used type. It is readily adaptable for ordinary spot welding on most weldable metals and is generally available in three types of operation: air, foot, and mechanical (motor or cam). It has a capacity of two pieces of approximately 13-gage (0.089-inch) SAE 1020 steel, a throat depth of from 12 to 36 inches, and a transformer capacity from 5 to 50 kVA.

Foot-operated machines (Figure 7-9) are best suited for miscellaneous sheet metal fabrication, particularly where the runs are not

Figure 7-7 Graphical representation of various resistance spot-welding cycles, showing relation of time for each segment and relative values of welding current and electrode force for each segment. (By permission, from *Metals Handbook* Volume 6, Copyright American Society for Metals, 1971.)



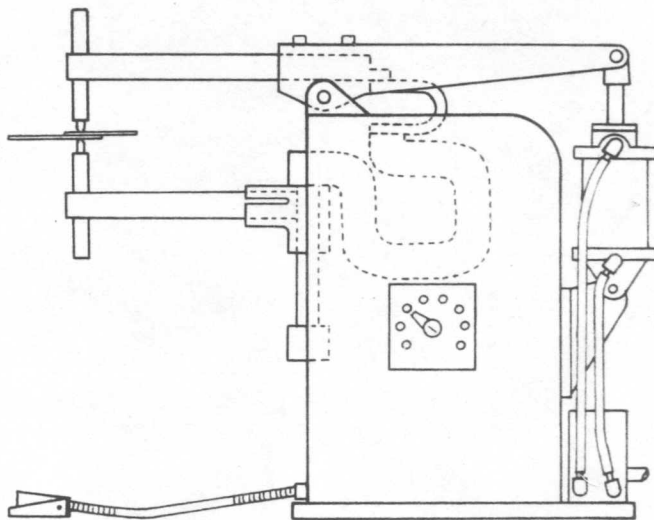


Figure 7-8 Standard air-operated rocker-arm spot-welding machine. (Redrawn by permission from American Welding Society. *Welding Handbook*, 6th ed., 1970, section 2, p. 28.5.)

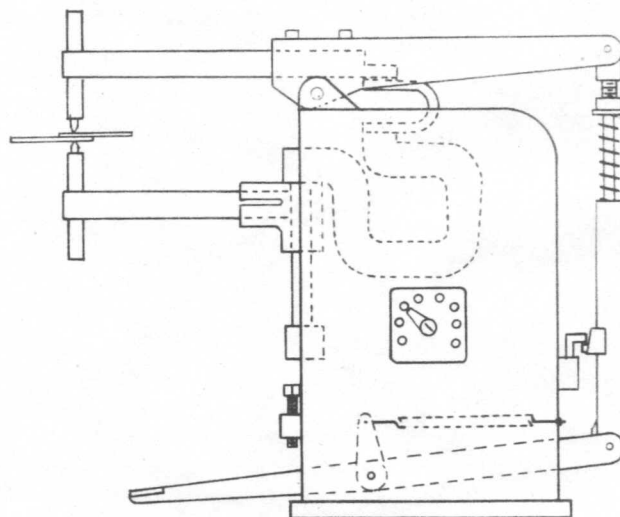


Figure 7-9 Foot-operated rocker-arm spot-welding machine. (Redrawn by permission from American Welding Society. *Welding Handbook*, 6th ed., 1970, section 2, p. 28.4.)

long. Motor-operated machines (Figure 7-10) are ideal for long production runs, where compressed air is at a premium or not readily available. Air-operated machines are the most popular type of rocker-arm machine and are not limited in operation by operator fatigue.

7-2 ROLL-SEAM WELDING

Roll-seam welding, or *seam welding*, as it is commonly called, consists of making a series of overlapping spot welds. Such a weld is normally gas and liquid tight. Two rotating circular electrodes (electrode wheels), or one rotating and one bar-type electrode (Figure 7-11) are used for transmitting the current. In this latter arrangement, the process is referred to as *butt-seam welding*. All roll-seam welds (Figure 7-12) are lap welds. There are two general types of seams: longitudinal and circular.

A longitudinal machine [Figure 7-13(a)] has its electrodes arranged to feed the work into the throat of the machine. Circular machines [Figure 7-13(b)] have the electrodes arranged to feed the work across the throat of the machine. A universal machine is one in which the electrodes may quickly be changed over from longitudinal to circular or vice versa.

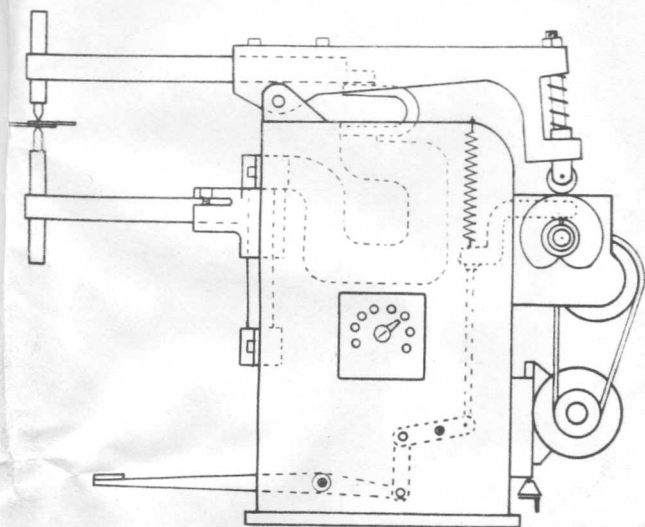


Figure 7-10 Motor-operated rocker-arm spot-welding machine. (Redrawn by permission from American Welding Society. *Welding Handbook*, 6th ed., 1970, section 2, p. 28.7.)

7-3 PROJECTION WELDING

In the projection welding process (Figure 7-1), current and heat flow are localized at a point or points predetermined by the design or configuration of one or both of the two parts to be welded (Figure 7-14). Spherical projections are used for welding assemblies made of steel sheet and plate. Projections can also be coined or forged on the ends or faces of screws, nuts, and similar fasteners (Figure 7-15).

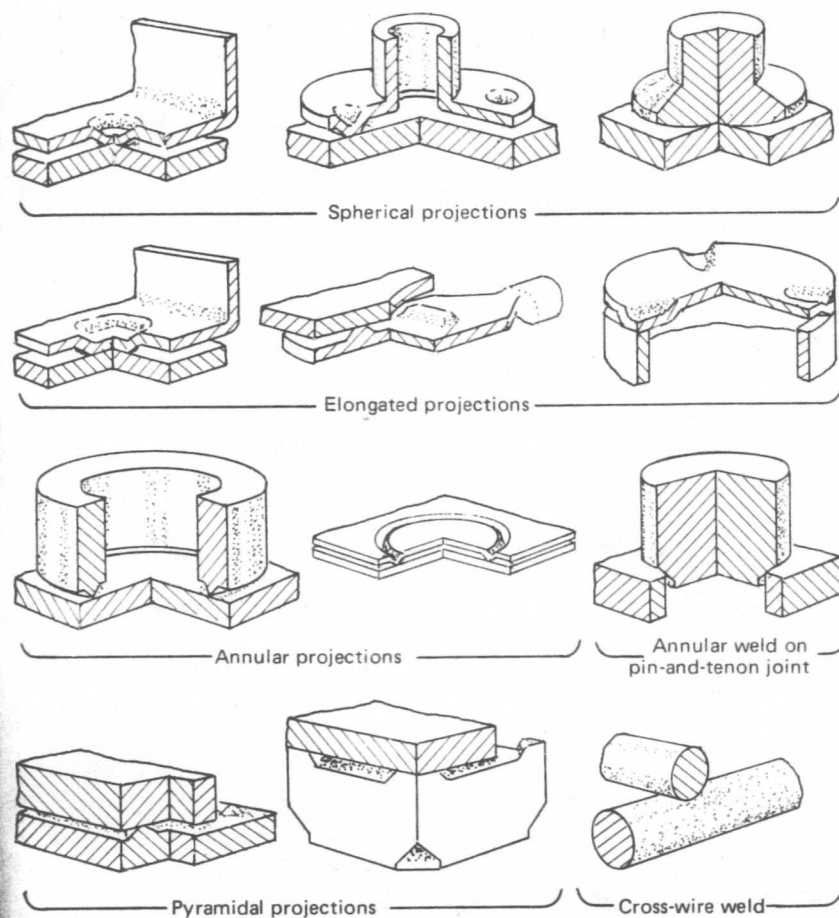


Figure 7-14 Variations on basic types of projections in projection welding. (By permission, from *Metals Handbook* Volume 6, Copyright American Society for Metals, 1971.)

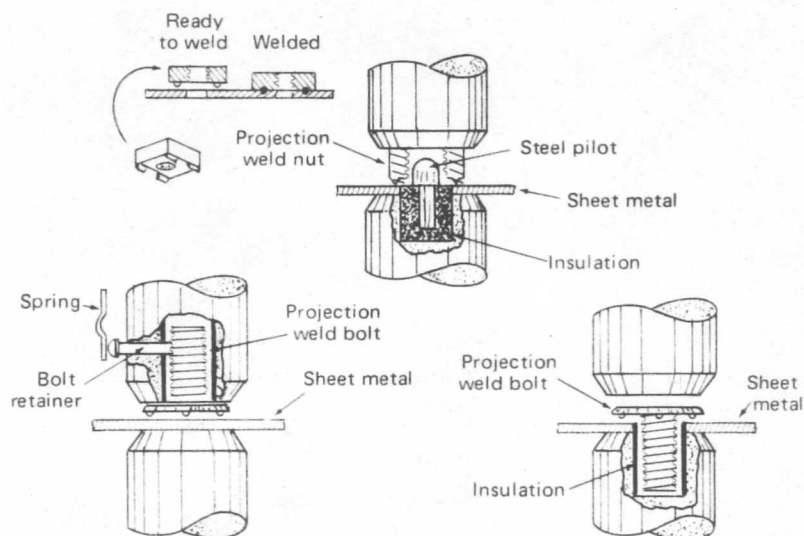


Figure 7-15 Projection-welded square nuts and studs. (Redrawn from *Resistance Welding, Designing, Tooling and Applications* by W. A. Stanley. Copyright 1950 McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company.)

Elongated projections are often used instead of spherical projections, where the shape of the parts makes an elongated weld more suitable and where welds made with spherical projections will not meet strength requirements. Annular projections are used for welding tubing to sheet metal, for making liquid-tight or gas-tight connections, as in attaching mounting studs to liquid reservoirs, and for joining thin sheet metal parts in cases where spherical projections may collapse during welding. Pyramidal projections are coined or forged on the face of nuts. Cross-wire welds (Figure 7-16) are used in making wire projects, such as cylindrical wire baskets and circuit boards. Projection-welding machines (Figure 7-17) are similar in principle to the press-type spot-welding machines discussed in section 7-1.

The metal that can be projection welded most satisfactorily is low-carbon steel (0.20% carbon maximum) with a section thickness between 0.010 and 0.250 inch. Naval brass, monel (nickel-copper), and austenitic stainless steels in any combination of two can also be successfully welded. Although coated metals, such as terneplate, tin plate, and aluminized steel, can also be welded, electrode pick-up necessitates frequent cleaning and redressing of the electrodes.

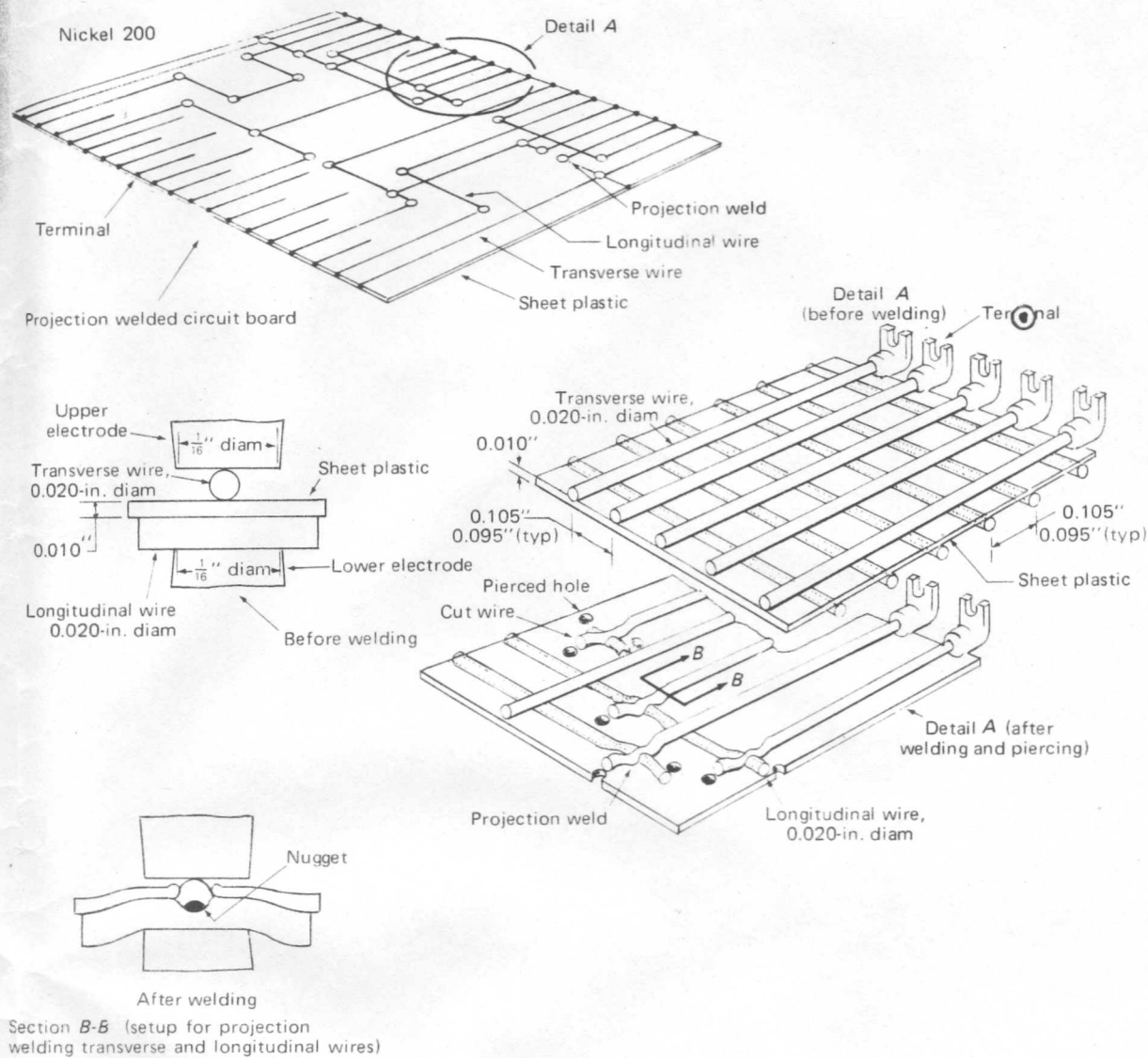


Figure 7-16 Projection-welded circuit board. (By permission, from *Metals Handbook* Volume 6, Copyright American Society for Metals, 1971.)

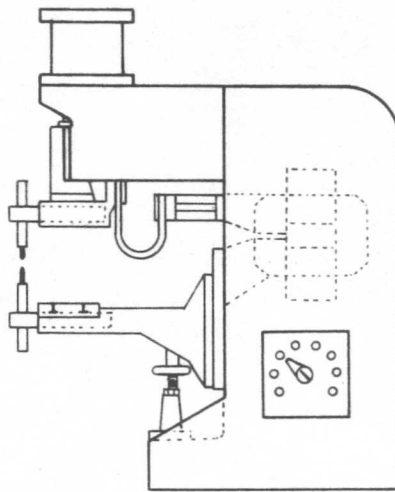


Figure 7-17 Typical press-type combination spot- and projection-welding machine. (Redrawn by permission from American Welding Society, *Welding Handbook*, 6th ed., 1969, section 2.)

7-4 ELECTRODES FOR SPOT, SEAM, AND PROJECTION WELDING

The electrodes used for these processes perform three important functions:

1. They conduct the welding current to the work.
2. They transmit the proper pressure or force to the weld area to produce a satisfactory weld.
3. They dissipate the heat from the weld zone more or less rapidly, depending on the process being employed and the necessity for removal of heat.

The first of these functions is electrical. If the application of pressure did not have to be considered, suitable electrode selection could be made almost entirely on the basis of electrical and thermal conductivity, taking into account the resistance of the electrode itself and the resistance between the electrode and the work surface at the area of contact.

The second function is mechanical. During welding operations, the electrodes are often subjected to considerable stresses, and they must withstand these stresses at high temperatures without excessive deformation. This is so because the current must not only be conducted to the work but must also be localized within a fixed area.

The transmitted pressure not only forges the heated workpieces together, but also restricts the passage of welding current to the localized area.

The conductivity of the electrodes must be higher than that of the metals being welded because, in addition to conducting electricity, the electrodes also conduct heat away from the exterior surfaces of the weld material. This function is very important because it is used in reverse when dissimilar metals are being welded to obtain a heat balance. The heat balance is obtained by using electrodes with lower heat conductivity than the weld metal to prevent too rapid heat dissipation from one of the metals of a dissimilar combination. This procedure is also useful when heat-treatable parts are to be welded.

Successful performance of any resistance welding operation, however simple or complicated it may be, is dependent upon the use of correct electrodes. The RWMA (Resistance Welder Manufacturers' Association) has classified electrode materials into two composition groups: copper-base alloys and refractory metal compositions. The alloys are available in the form of bars, forgings, castings, and inserts. They are sold under a number of trade names (Table 7-1). The general recommendations of the RWMA for the selection of the proper electrode material for spot welding similar and dissimilar materials are given in Table 7-2.

Electrode face shapes have been standardized (Figure 7-18) and are identified by the code developed by the RWMA for that purpose. The minimum face diameter for type A, B, D, and E electrodes can be determined by using the formula

$$\text{Face diameter} = 0.10 + 2t$$

where t = the thickness (in inches) of the base metal contacting the electrode.

Electrodes designed for spot welding can be used for projection welding if the electrode face is large enough to cover the projection being welded or the pattern of projections being welded simultaneously by the electrode.

Electrode wheels are available with standard face contours (Figure 7-19) and, depending on the machine size, they have the common widths and diameters in inches listed in Table 7-3.

7-5 FLASH WELDING

Flash welding is a resistance butt-welding process in which two workpieces are clamped in suitable current-carrying fixtures that hold them end to end in very light contact (Figure 7-20). Electric current is made to flow through the workpiece to produce flashing (arcing) which, in combination with electrical resistance, heats the abutting ends to the fusion point. When the abutting ends reach the

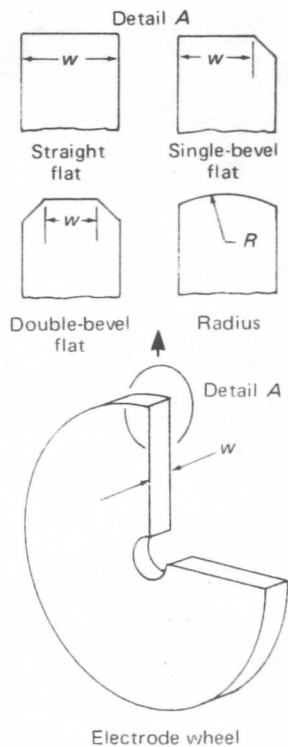


Figure 7-19 Standard face contours of seam-welding electrode wheels. (By permission, from *Metals Handbook* Volume 6, Copyright American Society for Metals, 1971.)

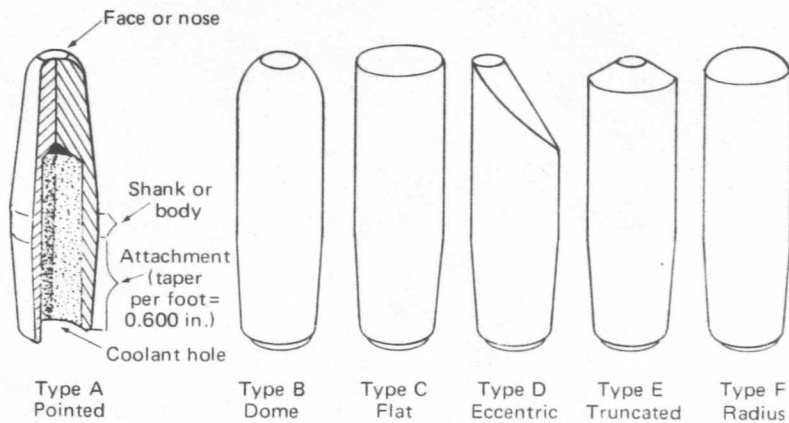


Figure 7-18 Standard types of electrode face or nose shapes. (By permission, from *Metals Handbook* Volume 6, Copyright American Society for Metals, 1971.)

Table 7-3 Common sizes of electrode wheels used for resistance seam-welding

MACHINE SIZE	WHEEL DIAMETER, IN.	WHEEL WIDTH, IN.
Small	7	$\frac{3}{8}$
Medium	8	$\frac{3}{8}$ – $\frac{1}{2}$
Large	10–12	$\frac{3}{8}$ – $\frac{3}{4}$

Source: By permission, from *Metals Handbook* Volume 6, Copyright American Society for Metals, 1971.

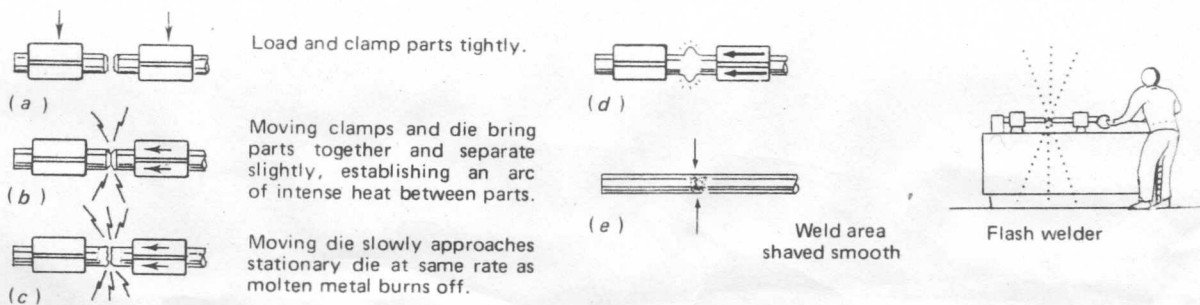


Figure 7-20 Typical flash-welding operation. (Redrawn from *Resistance Welding, Designing, Tooling and Applications* by W. A. Stanley. Copyright 1950 McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company.)

proper temperature for the correct depth, the workpieces are suddenly brought together with sufficient force to cause an upsetting action. The upsetting action pushes the molten metal and part of the plastic metal out of the weld area into a weld upset. In many applications (Figure 7-21), the upset must be removed after welding by scarfing or machining.

Flash welding can be used for joining many ferrous and nonferrous alloys (see Table 7-4), except for cast iron, lead, tin, zinc, bismuth and antimony alloys.

Some specific applications of flash welding are: miter joints between window frame extrusions, extremely large crankshafts (14-ft long 8-in. diameter at the main bearings), jet engine mounts, steel bars for contour roll forming of automotive wheel rims, and others (Figure 7-21).

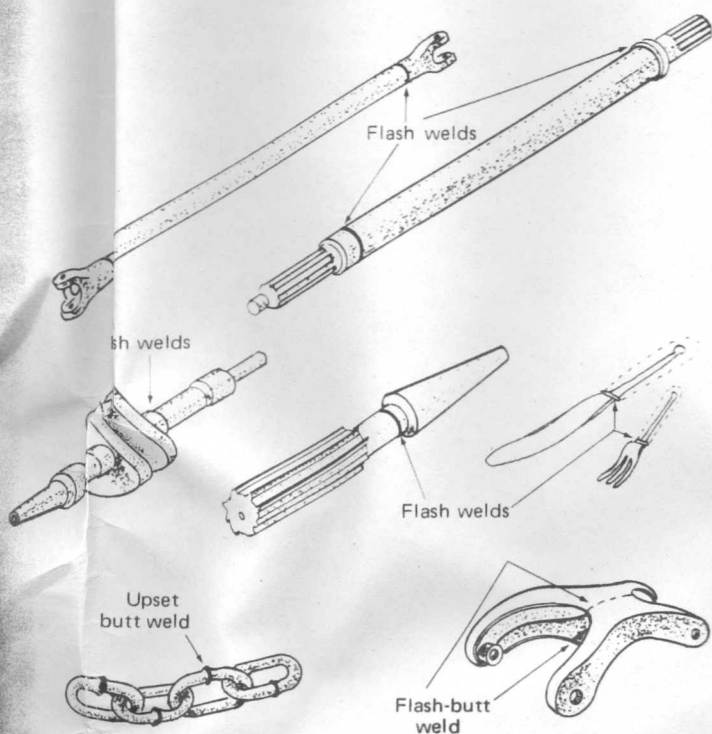


Figure 7-21 Examples of flash butt-welding applications. (Redrawn from *Resistance Welding, Designing, Tooling and Applications* by W. A. Stanley. Copyright 1950 McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company.)